APPENDIX G

SEAFOOD TAINTING PLAN

G.1 Overview for Managing Seafood Concerns During an Oil Spill

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The following material is drawn largely from three documents:

Mearns, A.J. & R.Yender, 1997. A summary of a NOAA workshop on management of seafood issues during an oil spill response. Proc. Arctic and Marine Oil Spill Program Technical Seminar. Environment Canada, Vancouver, pp. 203-214.

Reilly, T.I. and R.K York. 2001. Guidance on Sensory Testing and Monitoring of Seafood for Presence of Petroleum Taint Following an Oil Spill. NOAA Technical Memorandum NOS OR&R 9.107pp.

Yender,R., J. Michel, and C. Lord. 2002. Managing Seafood Safety After an Oil Spill Seattle: Hazardous Materials Response Division., Office of Response and Restoration, National Oceanic and Atmospheric Administration. 72 pp.

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Seafood safety is a concern raised at nearly every oil spill incident of any significance. Both actual and potential contamination of seafood can substantially affect commercial and recreational fishing, subsistence seafood use and generate public health concerns. Loss of confidence in seafood safety and quality can impact seafood markets long after any actual risk to seafood from a spill has subsided, resulting in serious economic consequences. Protecting consumers from unpalatable and unsafe seafood is a primary objective of federal and state public health agencies after a spill occurs.

The purpose of this guidance is to identify the various problems that can arise and to describe the remedies available. The information is aimed primarily at those in the fisheries sector suffering economic loss as well as spill responders and managers with responsibilities for protecting public health, and consumers concerned about the safety and quality of seafood. Interested parties are encouraged to share experience gained in managing fishery resources during oil spills.

Seafood managers may be faced with making many urgent decisions after an oil spill, often based on limited data:

Should seafood harvest in the spill area be closed or restricted?

If closed, what criteria should be applied to re-open a fishery?

How should seafood safety and palatability be evaluated?

How can health risks best be communicated to the public?

Public health officials and other seafood managers do not routinely deal with oil spills as part of their day-to-day responsibilities. Consequently, they typically have little experience with risks to seafood from oil spills when they suddenly are faced with determining appropriate seafood management actions in response to a spill.

Subsequent to an oil spill, there are three separate areas of concern that are often grouped together under the broad definition of "seafood tainting." The Unified Command will need to adequately address each issue in turn as well as the pertinent stakeholders. These three areas can be loosely outlined as follows:

- **Seafood Tainting Concerns**: Contamination of seafood can usually be detected as a petroleum taste, or taint. Public confidence in seafood products can quickly erode as a result of suspect, or actually contaminated products reach the market. The presence of taint simply indicates that flavor or odor is altered; it does not characterize the nature of the off-flavor or off-odor, quantify the degree of taint, or imply any human health hazard. Although health concerns are usually generated from seafood taint, "tainting" is primarily a marketing concern regarding the salability of seafood. It is reasonable to conclude, with respect to oil spill contamination, that if seafood is not "tainted," it is acceptable for consumption.

  Seafood tainting panels can be established on a spill-specific basis by contacting the U.S. Food and Drug Administration. Additionally, the U.S. Coast Guard can close a particular "area of operation" to fishing and/or seafood harvest as a part of the emergency powers of an oil spill.

- **Public Health Concerns:** The occurrence of contamination in seafood organisms or products following an oil spill can lead to public health directives being involved because of the presence of known carcinogenic compounds in petroleum products. The aromatic fractions of oil contain the most toxic compounds, with polycyclic aromatic hydrocarbons (PAH) being of greatest concern. The California Department of Health Services (CDHS; see **Appendix A**) should be contacted to determine chemicals of concern as well as testing levels. Additionally, the CDHS can coordinate the closure and reopening of areas and fisheries for public health reasons.

- **Trustee Agency Concerns:** Many finfish, shellfish, mollusks, and crustaceans can become contaminated during an oil spill. Petroleum contamination of finfish and shellfish depends upon a variety of biological and ecological factors, including feeding strategies, habitat utilization, and physiology. The ecological and population impacts of a spill will be species and habitat specific. The California Department of Fish and Game (CDFG) has the primary state trustee authority for these resources and can be contacted to determine if biological and ecological factors are a concern for a given resource. Additionally, the CDFG can close any fisheries under its jurisdiction for population health concerns.

Fishing is important in all maritime nations and many oil spills cause damage to subsistence, recreational and commercial fishing activity. Aquaculture enterprises have become widely established, thereby increasing the sensitivity of many coastal areas to oil pollution impact. Increased public awareness and heightened food quality and safety standards have meant that even small oil spills can cause a large impact and generate strong political interest.

Oil pollution effects take a variety of forms. Animals and plants may be killed as a result of oil smothering and toxicity. Catches and cultivated stock may become physically contaminated or acquire a taint. Fishing and cultivation gear may be oiled, leading to the risk of catches or stock becoming contaminated or fishing being halted until gear is cleaned or replaced. The handling of seafood products in bulk means that it is seldom practical to locate and remove the oiled specimens.

Fishermen and aquaculture operators are often on the front line of oil spill impact, but equipment suppliers, transporters, wholesalers and others are also involved in the process of bringing seafood produce to the market. Government authorities have a duty to protect public health and ensure that seafood products reaching the consumer are safe and palatable. A number of management strategies are available to prevent or minimize oil pollution impact on fishing and aquaculture activity. Fishing and harvesting restrictions can be imposed to prevent contamination of fishing gear and to protect consumers and markets. Such measures also provide time for evaluating risks and for organisms and their habitat to recover from oil contamination.

Oil spill impact on seafood resources

The impact of an oil spill on marine life depends largely on the physical and chemical characteristics of the oil and the way these change with time, a process known collectively as “weathering”. The main physical processes which act on the oil during the course of a spill are evaporation, natural dispersion and, to a lesser extent, sedimentation. Specific gravity, viscosity, chemical composition and toxicity of the pollutant and the way they change with time tend to determine the degree of oil exposure for seafood organisms. The prevailing weather and sea conditions will determine the movement of spilled oil. Clean-up activities such as the use of chemicals or aggressive washing techniques can also affect the fate of oil. Thus, a variety of factors combine to define the character of a particular oil spill and the fate of sensitive resources in its path.

Adult free-swimming fish, squid, shrimp and wild stocks of other commercially important marine animals and plants seldom suffer direct harm from oil spill exposure. This is because only rarely will oil concentrations in the water reach sufficient levels to cause tainting or mortality. The greatest impact is found on shorelines and shallow waters where animals and plants may be physically coated and smothered by oil or exposed directly to toxic components in the oil. Edible seaweeds and sea urchins are examples of shoreline species that are especially sensitive to smothering and oil toxicity, respectively. Apart from direct effects, oil may cause more subtle long-term damage to behavior, feeding growth, or reproductive functions. It is a complex task to isolate these sublethal pollution effects from the influence of numerous other factors.

As a general guide, dispersants should not be used close to aquaculture facilities or spawning grounds and nursery areas. Stripping oiled seaweed from rocks and indiscriminate hot water washing are examples of aggressive response techniques that can affect commercially exploited species and delay natural recovery.

Fishing and aquaculture activities

Oil can foul the boats and gear used for catching and cultivating commercial species. Flotation equipment, lift nets, cast nets, and fixed traps extending above the sea surface are more likely to become contaminated by floating oil, whereas lines, dredges, bottom trawls and the submerged parts of cultivation facilities are usually well protected, provided they are not lifted through an oily sea surface or affected by sunken oil.

Seaweeds, shellfish and cultivated animals kept in cages or tanks are usually unable to avoid contact with oil contaminants in the water and the presence of oil pollutants may significantly add to the stresses already imposed by keeping animals in artificial conditions. Floating oil may physically coat fish-farming facilities, and unless they are rapidly cleaned they may act as a longer-term source of stock re-contamination.

There are many complex influences on the health of cultivated organisms and observed effects may be the result of a combination of factors. If, for example, the stocking density or the water temperature in a fish farm is unusually high, there is a greater risk of mortality, disease or growth retardation occurring as a result of oil contamination.

The cultivation of seaweed, fish, crustaceans, mollusks, echinoderms and sea squirts frequently involves the use of onshore tanks to rear the young to marketable size, or to a size and age suitable for transfer to the sea. Such facilities are usually supplied with clean seawater drawn through intakes located below the low water mark. The intakes may occasionally be under threat from sunken oil or dispersed oil droplets, which may lead to contamination of pipework and tanks and the loss of cultivated stock.

Fishing and seafood cultivation are not always pursued throughout the year and seasonal differences in sensitivity to oil spills can therefore occur. The collection of wild seed, or the rearing of larvae in onshore tanks supplied with water piped from the sea is one example of seasonal activity.

Tainting

The contamination of seafood can usually be detected as a petroleum taste, or taint. Public confidence in seafood products can quickly erode as a result of suspect, or actually contaminated, products reaching the market. Filter-feeding animals such as bivalve mollusks are particularly vulnerable to tainting since they may easily ingest dispersed oil droplets and oiled particles suspended in the water column. Animals with a high fat content have a greater tendency to accumulate and retain petroleum hydrocarbons in their tissues.

A taint is commonly defined as an odor or flavor that is foreign to a food product. Background concentrations of oil in water, sediment and tissues are highly variable and both the degree of taint that may result and consumer tolerance levels for taint are different for different seafood products, communities and markets. The presence and persistence of taint will depend mainly on the type and fate of oil, the species affected, the extent of exposure, hydrographic conditions and temperature. Tainting of living tissue is reversible but, whereas the uptake of oil taint is frequently rapid, the depuration process whereby contaminants are metabolized and eliminated from the organism is slower.

The concentrations of hydrocarbons at which tainting occurs are very low. Some of the chemical components in crude oils and oil derivatives with the potential to cause tainting have been identified but many are unknown and no reliable threshold concentrations for petroleum-derived tainting agents have been established. Hence it is not possible to determine by chemical analysis alone whether a product is tainted or not. However, the presence or absence of taint can be determined quickly and reliably by sensory testing, when a trained panel and sound testing protocols are employed. Sensory testing is further described below.

Public health concerns

The occurrence of contamination in seafood organisms or products following a major spill has potentially damaging implications for marketing and can lead to public health directives being invoked because of the presence of known carcinogenic compounds in petroleum products. The aromatic fractions of oil contain the most toxic compounds, and among these it is the 3- to 7-ring polycyclic aromatic hydrocarbons (PAH) that command greatest attention.

The input of potentially carcinogenic PAH stems largely from combustion sources and petroleum and, for the human population, exposure to PAH is primarily from food. However, in common with other potentially carcinogenic pollutants, it is not possible to define a concentration threshold of potential carcinogens in seafood products that represents a risk-free intake for humans. Furthermore, a wide variety of smoked food, leafy vegetables and other dietary components also contain the same PAH compounds. The detailed composition of the diet determines which food items are major contributors for individual consumers. It is important to recognize that different regions and ethnic groups have varying levels of seafood in their diets.

Generally, PAH levels in foods are not subject to legislative limits, although limits exist for some compounds in drinking water. The risk to an individual or community from oil spill-derived carcinogens should be assessed in the context of the overall exposure from all potential sources, which is subject to many variables. From a general risk evaluation of the amount, frequency and duration of PAH exposure following oil spills, most studies have led to the conclusion that oil spill-derived PAH contamination of seafood is not a significant threat to public health. However, it is important to note that while toxicologists have assessed the threat to public health as negligible, it may be difficult to convince local users, fish buyers and consumers in general, especially when there is an option of buying seafood from other locations.

A further complication for food safety and quality controllers is that a seafood diet is inherently nutritious and rich in protein and vitamins. Restrictions on seafood intake can cause consumption patterns to shift toward less healthy diets. Other forms of contamination, such as heavy metals, algal toxins, pathogenic bacteria and viruses, also affect seafood safety and quality. The potential impact of an oil spill on public health must be viewed in a wider context in order to identify and implement appropriate strategies.

Oil spill protection and clean-up response options

Booms and other physical barriers can sometimes be used to protect fixed fishing gear and aquaculture facilities, although in most cases it is impossible to prevent damage altogether. Fishing and cultivating equipment is often purposely sited to benefit from migration routes or efficient water exchange. Such locations are characterized by fast water flow, which is where booms will not perform well.

Sorbent materials are often useful for removing oil sheens from water and tank surfaces. Sorbent booms are easy to deploy and move, and serve to control sheens in floating cultivation pens. However, oil-saturated sorbents should be replaced regularly to avoid them becoming a source of secondary pollution. Another potential concern when dealing with aquaculture facilities is the risk of spreading disease with booms and other equipment moved from one location to another.

Dispersant should be used with care so as not to cause tainting of shellfish and captured or cultivated stock. As a general guide, it is not prudent to use dispersant in shallow waters where fishing or aquaculture is important. However, if used at a safe distance, dispersants can reduce or prevent contamination of equipment by floating oil. It is difficult to define in general terms what represents a safe distance since this will depend on dilution rates and the strength and direction of prevailing currents.

The remedial methods employed should be chosen with care, so as not to make matters worse. Almost all clean-up techniques cause damage, which should be taken into account when considering the merits of removing oil pollution from an affected area. For example, attempts at cleaning intertidal mudflats can cause long-term disruption and damage to the habitat of cockles and clams. There are occasions when it is better to rely on natural recovery processes for oiled habitats than to inflict more damage from clean-up measures known to be futile.

Sensory testing

Oil-tainted food is unpalatable even at very low levels of contamination, which provides a safety margin in terms of public health. As a generalization, if seafood is taint-free, it is safe to eat. Properly conducted sensory testing is the most efficient and appropriate method for establishing the presence and disappearance of tainting, and for indicating whether seafood is fit for human consumption. The International Standards Organization (ISO) provides information on the training of sensory evaluation panels. A trained sensory panel using properly prepared samples and a written testing protocols are essential elements in sensory testing in order to obtain reproducible results. In some cases of potentially unsafe seafood it may be appropriate to avoid taste tests and instead focus on olfactory testing.

A sampling program with defined objectives will often be necessary to determine the degree, spatial extent and duration of the oil contamination problem. The aim is to take and analyze the number of samples necessary to obtain statistically reliable results. Target species are those of commercial, recreational or subsistence fishing value and which are commonly consumed. Samples of animal and plant tissue are perishable and must be secured and stored so as to preserve their integrity. Control samples from a nearby area unaffected by oil pollution are important for reference purposes and to eliminate the interference of background contamination, but are difficult to find in practice. In the case of commercial species it is sometimes possible to obtain reference samples from the marketplace. If appropriate reference samples cannot be obtained, a trained panel of expert testers should nevertheless be able to determine when seafood is taint-free.

In principle, a relatively small number of samples are sufficient to confirm the initial presence of taint and define the affected area in order to introduce a restriction. Monitoring the progressive loss of taint, by sampling at appropriate intervals thereafter, allows the point at which taint disappears to be determined with some confidence. The oil type would determine the frequency of sampling, the habitat and organisms affected, and the rate at which depuration was observed to occur. A time series of samples gives clues to depuration rates and allows future trends to be predicted. While it is not an absolute requirement to have reference samples in order to conduct a sensory evaluation, the taint-free threshold can best be defined as the point where a representative number of samples from the polluted area are no more tainted than an equal number of samples from a nearby area or commercial outlet outside the spill zone. Account should also be taken of levels considered acceptable in comparable seafood species being harvested in other areas of the country.

This approach is inherently fair and recognizes that tainted samples, not necessarily due to oil spills, can occur in any population. Once two successive sample sets over a short period of time remain clear, restrictions can be removed or the scope of the ban adjusted as a distinct area or species is shown to be free of taint. The confidence in accepting that the fish or shellfish are clean and safe following a particular spill comes from an adequate time-series of monitoring data showing the progressive reduction in taint.

Chemical analysis

In some cases, the chemical composition and the fate of the spilled oil, widespread subsistence fishing and aquaculture, or the presence of commercial shellfish resources in the path of the oil may argue for chemical analysis to be undertaken. Chemical screening for exposure can complement sensory evaluations and help validate sensory testing. Sensory evaluation does not preclude the need for chemical analysis and may serve as a screening tool for selecting samples for further chemical analysis.

It is widely recognized that to impose a single fixed standard for PAH levels in seafood by reference to baseline data is unworkable for several reasons. Baseline data are rarely available and unlikely ever to be applicable to the conditions prevailing during a particular oil spill. Background levels of hydrocarbons, where they are known, vary greatly and are subject to both pyrogenic and chronic anthropogenic input. PAH intakes in seafood meals also vary greatly between different communities, as do the perceived sensitivities of individual consumers. One viable approach is to ensure that samples should be taint-free. PAH levels in the samples may also be compared to reference samples collected just outside the affected zone or which are freely marketed elsewhere in the country. However, this may be difficult to implement in areas that are known for their "pristine" seafood.

Analysis of water and sediment is usually not necessary since the condition of seafood organisms inhabiting water and sediment environments is of primary interest. In any case, the organisms effectively “monitor” the condition of their surrounding environment by the process of accumulating and depurating contaminants, and if they remain viable then there is little need to monitor other components. In cases where animals or plants are continuously re-contaminated from an invisible or unknown source it may be appropriate to attempt to monitor the pathway of oil contamination. However, reliable interpretation of analytical data from sediment samples can be difficult if there is a wide range of other contaminants present.

Costs and compensation

When it proves impossible to protect fishing gear and cultivation facilities from oil contamination, the choice becomes one of cleaning, repairing, restoring or replacing the affected item, facility or habitat.
In some situations compensation arrangements may exist, allowing fishermen and aquaculture operators to be reimbursed for costs incurred and losses suffered. Claimants will be expected to provide evidence of the losses, such as receipts of payments made and records of income in previous years.

The complexities of biological systems and business interactions often make it difficult to separate the actual impact of an oil spill from other influences. Reliable catch statistics are rarely available in sufficient detail to enable oil spill effects to be isolated from other influences such as variable fishing effort and natural fluctuations in the stock. Only with expert knowledge of local circumstances, careful investigation and comparisons with nearby unpolluted areas can the true causes of observed damage be determined. In the case of subsistence fishing no financial transactions may be involved, so catch records are unlikely to be available. However, it should be possible to quantify subsistence loss in bartering terms or with other market-based substitutes.

Economic loss resulting from mortality of cultivated organisms may need to be quantified at several levels. The first level is the immediate mortality and loss suffered by the grower. This may simply be a question of counting and weighing the casualties, documenting any reduction in growth rate, and calculating any financial losses from projected harvests and from closed or under-utilized aquaculture facilities. Depending on the magnitude of the event and the availability of suitable substitutes, losses may also be suffered by processors, transporters, wholesalers and retailers. In a large or notorious incident actual or perceived tainting may result in short and long-term loss of markets and reduced prices across broad geographic regions. Quantification of these impacts can be complicated and may involve not only the direct losses, but also the advertising costs incurred to limit the harm to a region's reputation.

Management strategies for protecting seafood resources

The simplest management strategies involve no intervention beyond monitoring the evolution of an oil spill and any threat to seafood safety. Low-key intervention can take the form of advisory information or the issuing of guidelines to the seafood industry. Stricter measures include retail controls, impoundment of catches and seafood products, activity bans and fishery closures.

All management options have drawbacks or indirect effects and a careful review of the various facets of an oil spill is to be recommended before any actions are taken. Commercial fishing creates complex changes in the abundance and distribution of the exploited species. Any sudden change in the fishing effort is therefore likely to affect population densities. Thus, while most oil spill management strategies undoubtedly cause business interruption and financial loss, some fishery closures have also resulted in beneficial stock conservation, particularly where the exploited species have been non-migratory.

Preferred management strategies reflect cultural and administrative traits in different countries. In Asia there are few reported instances of tainting or seafood contamination following oil spills. Formal closures or activity bans are seldom, if ever, introduced. Instead voluntary suspension of fishing in oil-polluted areas is the norm. The voluntary suspension typically lasts a few weeks until the gross oil contamination of shorelines has disappeared or has been removed. In most cases, fishing and harvesting are resumed without any ill effects in terms of tainting, public health or market confidence.

During an oil spill it is vital to communicate information to the media and the public in an effective manner on the likelihood of adverse consequences for fishery resources. Inaccurate public information about tainting and contamination may limit the range of management strategies available, causing unnecessary fishing and harvesting restrictions and/or loss of consumer confidence in the market. Risk communication is an ongoing process that must be addressed in both spill response planning as well as during the spill event. Information about risk can be communicated through a variety of channels, from media reports to public meetings. Several resources provided in Appendix F can provide further information on successfully communicating risk to the media and public.

The media can play a valuable role in promoting a rational reaction to temporary disruptions. For example, where a properly conducted sampling and testing regime provides clear evidence that seafood is safe, the media provides the vehicle for getting this message to the consumer. The needs of the media are best served by providing factual information and by clearly justified decisions. Contingency planning provides the best opportunity for managers to select an appropriate strategy and implement the most effective response for dealing with a threat to seafood safety and quality.

Fishing and aquaculture procedures

In addition to standard spill response measures, there are management options that may help minimize contamination and financial losses. Options include moving floating facilities out of the path of slicks, sinking of specially designed cages to allow oil to pass, and transfer of stock to areas unlikely to be affected. The opportunities to use these approaches are likely to be rare for a range of technical, logistical and cost considerations, but in the right circumstances and with planning they may be practicable.

Temporarily suspending the replenishment of seawater drawn in from the sea and re-circulating water already within the system may be an effective method of isolating stock cultivated in shore tanks or ponds from the threat of oil contamination. Closing sluice gates to prawn ponds, for example, can also afford short-term protection, but care must be taken to ensure that the build-up of noxious waste products in stagnant or re-circulating water over time does not cause mortalities. Suspension of feeding is another way of reducing the risk to farmed fish and other cultivated stock from coming into contact with floating oil or contaminated feed. In land-based facilities the reduction or suspension of feeding has the advantage that the loading of waste products in the re-circulated water is reduced.

For such measures to be effective it is vital that sensitive fishing and aquaculture facilities are identified in local area contingency plans and that key personnel are notified in the event of an oil spill in their area. The plans can also identify optimal response options and the sources of necessary materials and equipment. The preparation and maintenance of such plans are normally the responsibility of local government authorities or operators of local oil-handling facilities.

In some cases aquaculture operators may face the risk of ultimately losing all the stock due to oil spill damage. Harvesting before the stock becomes oiled might be possible, albeit selling the products at a lower price, and thereby salvaging some of its value. Conversely, normal harvesting could be delayed to allow contaminated stock to depurate and become taint-free.

Where fish are caught by anglers for sport, sufficient protection can sometimes be provided simply by issuing advice against consuming the catch and for recreational fishermen to adopt a catch-and-release policy.

Fishing and harvesting restrictions

Government restrictions on fishing activity are often unrelated to oil spills and are imposed as a means of stock conservation or to ensure fair competition among fishermen. Fishing may be restricted to certain periods and locations, with closures often coinciding with breeding seasons and sites to encourage natural stock replenishment. Catches may be restricted to certain quantities or quotas in a given period. Temporary closures of fisheries are imposed to protect consumers from health hazards when water and sediment quality or a seafood resource has become degraded by pollutants, natural toxicants or microorganisms.

Fishery closures can be imposed after an oil spill in order to prevent or minimize fishing gear contamination and to protect or reassure seafood consumers. Fishermen can agree to a voluntary suspension of fishing activity as a precautionary measure during a period when oil is drifting in their normal fishing area, and thereby avoid repeatedly contaminating fishing gear. Alternatively, a fishery may be protected by extending existing closures or imposing additional bans, but there are likely to be secondary consequences from all these measures.

Fishery closures imposed to protect equipment and catches can generally be lifted once the sea surface is visually free of oil and sheen, and there is no problem with sunken oil. Aerial surveillance is the most reliable way of checking sea surface conditions. Restrictions imposed on the basis of proven tainting are likely to be more prolonged and require careful monitoring. In most oil spill scenarios a fisheries and aquaculture management protocol consisting of a visible-sheen test and sensory tests will satisfy the demand for scientific credibility and provide adequate safeguards against unpalatable and unsafe seafood reaching consumers.

Credible decision-making with respect to fishing and harvesting restrictions should be based on sound scientific principles and common sense. Knowledge of fishery resource management is essential, as is an understanding of oil pollutants, their physical and chemical characteristics, likely biological impact, and background levels of contamination, both locally and nationally. Seafood consumption patterns and seasonal variations in trading and marketing will further help define a public health risk profile and allow regulators to form a considered opinion on risk management. It is vital to determine the criteria that will be applied for reopening a fishery before a ban is put in place. These criteria form an important part of contingency plans. It is also critical to assess the benefits accruing as a result of a closure against the losses that will ensue from closing or restricting normal fishing and cultivation activity.

Conclusions and recommendations

Oil spills can pose a significant threat to fishing and aquaculture resources. The main oil pollution effects are physical contamination of equipment, tainting and contamination of seafood, and economic loss from business interruption, including loss of consumer confidence. With effective contingency plans and spill response procedures, much can be done to prevent or reduce the impact of oil spills on fishing and aquaculture.

The repercussions of contaminated seafood on public perception can be serious unless the issues of market confidence and public health are properly managed. In most cases a management protocol consisting of a visible-sheen test coupled with sensory testing will provide adequate safeguards against unpalatable and unsafe seafood reaching consumers.

To maintain confidence in the fisheries sector there should be a sound strategy for implementing a fishery closure, based on scientific data, and a consistent application of management restrictions. An important component of oil spill contingency considerations is the need to determine re-opening criteria before deciding on whether to impose fishing and harvesting bans. Part of the rationale for introducing fishery closures is to minimize or prevent economic damage that might otherwise occur, as well as protecting the consumer. In such cases some form of economic appraisal is necessary in order to monitor the effectiveness of control measures from a cost-benefit viewpoint.

G.2 Decision Process for Managing Seafood Safety

The default position regarding management of seafood safety during an oil spill is to have no closure or other restrictions on seafood harvest. In some cases there may be an initial, temporary *de facto* closure if the U.S. Coast Guard establishes a safety zone restricting access in areas of active oil recovery. Fishermen also may voluntarily avoid working in oiled areas to prevent oiling their gear and catch. This initial period after a spill can provide an opportunity to evaluate spill conditions and conduct limited testing to determine whether a precautionary closure or other immediate restrictions on seafood harvest are warranted.

The first step for seafood managers after an oil spill has occurred is to collect and evaluate information on the nature of the spill. The spill response organization should be able to provide the following information almost immediately after the spill occurs:

- Overflight maps and trajectory analyses showing the present and predicted spread of surface slicks;
- Forecasts of weather and sea conditions that may affect the potential for oil to mix into the water column;
- Results of oil weathering models;
- Details about the oil type and expected behavior;
- Predictions of oil fate and persistence; and, some cases,
- Chemical results for water and sediment samples collected in the spill area.

Fishery management agencies and associations should be able to provide information on:

- Species being harvested now or in the near future;
- Geographical extent of the harvest areas;
- Harvest gear types in use; and,
- Data on background levels of PAH contamination in the spill area (from NOAA, California State Mussel Watch, and other monitoring programs).

Based on this information, seafood managers can assess whether the oil spill is likely to expose and contaminate seafood. If seafood is not at significant risk, then no harvest closures or other seafood restrictions are needed, and this determination is communicated to the public. Because spills are dynamic, conditions are monitored and risks to seafood reevaluated until the threat abates.

If managers determine that seafood may be affected, the next step is to assess whether seafood is tainted or contaminated to levels that pose a consumption risk to human health. Information that can help determine the impacts includes:

- Overflights and ground surveys identifying visible oil in seafood harvesting areas;
- Chemical analysis of water and/or sediment samples from the harvest area;
- Sensory testing of seafood samples from representative species and areas (both spill and reference areas);
- Chemical analysis of tissue samples from representative species and areas (both spill and reference areas); and,
- Data on background levels of oil-related contaminants.

Determining whether seafood has been contaminated can take time. Developing and implementing sampling plans, conducting sensory and/or chemical testing, and evaluating results may require weeks or longer. Monitoring continues and the risk assessment process is repeated as necessary.

If seafood is tainted or is contaminated to a level posing a potential health risk, the next step is to select the most appropriate seafood management action(s). Examples of management actions include seafood advisories, increased inspections of harvested seafood or fishing gear, harvest closures, and fishing gear restrictions. If a fishery is closed or otherwise restricted, seafood managers must establish criteria for determining when the seafood is palatable and safe for human consumption and that restrictions can, therefore, be lifted. No accepted international or federal criteria have been established for oil-related contaminants in seafood. State seafood managers generally have developed their own criteria for each spill, resulting in some inconsistencies among spills. Varying levels of background contamination also have contributed to inconsistencies in criteria applied.

Seafood Safety Management Authority

Typically, authority to manage seafood to protect human health resides with state health agencies. Many states routinely chemically analyze finfish and shellfish tissues for contamination as part of their water-quality monitoring programs. If a state concludes that eating contaminated finfish or shellfish collected from state waters poses an unacceptable human health risk, it may issue local fish consumption advisories or harvest closures for specific water bodies or parts of water bodies and specific species.

The Food, Drug, and Cosmetic Act authorizes the U.S. Food and Drug Administration (USFDA) to protect and promote public health. The USFDA's responsibilities include keeping "adulterated" food off the market. The USFDA has jurisdiction over seafood that crosses state lines in interstate commerce.

The Magnuson Act, 16 U.S.C. 1801 *et seq.*, authorizes NOAA's National Marine Fisheries Service (NMFS) to regulate fishing in federal waters (generally from 3-200 miles from shore). The act is targeted toward fishery conservation rather than protection of public health or economic concerns. Fishery management plans, developed under the authority of the Magnuson Act, specify any limitations imposed on fishing for federally regulated species. Limits on fishing are enforced by means of regulations published in the Federal Register, in compliance with the Administrative Procedures Act. In the event of an oil or chemical spill, publication of an emergency rule in the Federal Register is required to put an enforceable, official fishery closure in place and to make any modifications to the closure once it is put into effect. The Magnuson Act was recently amended to allow emergency action fisheries closures to remain in effect indefinitely. Previously, such closures were limited to two 90-day periods.

Specific Seafood Contamination Terminology

Adulteration

According to the U.S. Food and Drug Administration (FDA), a food is considered adulterated if it bears or contains any poisonous or deleterious substance that may render it injurious to health, if it contains any filthy, putrid, or decomposed substances, or if it is otherwise unfit for food (Federal Food, Drug, and Cosmetic Act, Section 402).

Taint

Taint is commonly defined as an odor or flavor that is foreign to a food product, including seafood (ISO 1992). According to this definition, the presence of a taint simply indicates that flavor or odor is altered; it does not characterize the nature of the off-flavor or off-odor, quantify the degree of taint, or imply health hazard.

Body Burden

The concentration of a contaminant in an organism, reported for the whole animal, or for individual tissues such as gonads, muscle, and liver, is referred to as the body burden. It can be reported on the basis of either wet or dry weight of the organism or tissue.

Uptake

Uptake is the process of contaminant accumulation in an organism. Uptake of oil can occur via the following mechanisms:

- Adsorption (adhesion) of oil on the skin.
- Absorption of dissolved components from the water through the skin (including interstitial water exposures for infauna).
- Absorption of dissolved components through the gills.
- Adsorption of dispersed oil droplets to the lipid surfaces in the gills.
- Ingestion of whole oil droplets directly or of food contaminated with oil, followed by sorption in the gut.

Many factors influence uptake, including the exposure concentration and duration, pathway of exposure, lipid content, and feeding and metabolic rates. Uptake from water generally occurs more quickly than dietary uptake or uptake from sediments.

Bioaccumulation

The net accumulation of a substance by an organism as a result of uptake from all environmental sources and possible routes of exposure (contact, respiration, ingestion, etc.) is termed bioaccumulation.

Bioconcentration

The net accumulation of a substance as a result of uptake directly from aqueous solution.

Biomagnification

The increase in body burden of a contaminant with trophic level is called biomagnification. PAHs generally do not biomagnify in finfish and shellfish because of their low dietary uptake efficiencies, on the order of 1 to 30%, reflecting slow kinetics and short residence time in the gut.

Elimination

All of the processes that can decrease tissue concentrations of a contaminant, including metabolism, excretion, and diffusive loss are collectively termed elimination. *Metabolism* is an active physiological process whereby a contaminant is biotransformed into metabolites. For PAHs, the metabolites are more water-soluble, which facilitates *excretion*, another active physiological process that eliminates contaminants (both parent compounds and metabolites) through bile, urine, or feces. *Diffusive loss* refers to a decrease in tissue burden caused by simple diffusion out of the organism, which is controlled by partitioning between tissue and water. The term *depuration* may be used for the mechanism of diffusive loss, and *elimination* may be used for the combined process of metabolism, excretion, and diffusive loss. These definitions are slightly different than those used by ASTM (1994), which defines depuration as “the loss of a substance from an organism as a result of any active or passive process” and provides no definition for elimination. However, the definitions given are more precise and will be followed in this document. Elimination can also include release of PAHs in lipid-rich eggs or gametes during spawning.

Elimination processes begin as soon as uptake occurs. In constant exposure experiments, body burdens tend to reach a “steady state” in which fluxes of the contaminant moving bi-directionally across a membrane or boundary between compartments or phases have reached a balance, not necessarily equilibrium. When the exposure decreases, elimination rates depend, in part, on the hydrophobic properties of the compound. The half-lives of individual compounds vary (see discussion below).

Growth Dilution

Growth dilution occurs when the rate of tissue growth exceeds the rate of accumulation, such that it appears as though elimination is occurring because the tissue concentration is decreasing. This process may be important when monitoring bivalves during the growing season.

Oils have been grouped into types with similar properties to help predict their behavior at spills. This same approach can be used to characterize the relative risk of contamination of seafood by oil type. Table II-2 summarizes the properties and risk of seafood contamination for the five oil groups commonly encountered by spill responders. These generalizations can be used when initially screening an incident to evaluate the potential for seafood contamination.

ASSESSING THE LIKELIHOOD OF SEAFOOD EXPOSURE AND CONTAMINATION

Each oil spill is a unique combination of conditions and events. Seafood is only at risk of contamination from a spill if it is exposed to the oil. Once exposed to oil, an organism becomes contaminated only to the extent it takes up and retains petroleum compounds. Factors that influence the potential for spilled oil to expose and contaminate seafood are discussed in this section.

Oil Types and Properties

Oil type and properties strongly influence whether seafood is exposed and contaminated. Crude oils and the refined products derived from them are complex and variable mixtures of hydrocarbons of different molecular weights and structures. They can contain hundreds of different compounds. All crude oils contain lighter fractions similar to gasoline, as well as heavier tar or wax fractions. Because of these differences in composition, different oils vary considerably in their physical and chemical properties. For example, consistencies of different crude oils vary, ranging from a light volatile fluid to a viscous semi-solid. Such differences in properties influence behavior of spilled oil and subsequent cleanup operations.

The petroleum hydrocarbons that comprise oil are composed primarily of hydrogen and carbon, but also can contain varying amounts of sulfur, nitrogen, oxygen, and trace metals. The three main fractions of hydrocarbon compounds in oils are saturates, aromatics, and polar compounds. The table below shows the properties and relative abundance of each fraction in different types of oil products.

Seafood contamination can result from exposure to the dissolved fraction of oil, dispersed oil droplets, or an oil coating. With regard to the dissolved fraction, the aromatic fraction of the oil poses the greatest exposure risk because aromatics are relatively more soluble than the other components in oil. Saturates are a major component of oil, but they have lower solubility and higher volatility compared to aromatics of the same molecular weight. Furthermore, saturates are virtually odorless and tasteless, and do not contribute to tainting.

Table G.2-1 Characteristics of oil types affecting the potential for seafood contamination

Gasoline products	Diesel-like products and light crude oils	Medium-grade crude oils and intermediate products	Heavy crude oils and residual products	Non-floating oils
Examples – Gasoline	Examples – No. 2 fuel oil, jet fuels, kerosene, West Texas crude, Alberta crude	Examples – North Slope crude, South Louisiana crude, IFO 180, lube oils	Examples – San Joaquin Valley crude, Venezuelan crude, No. 6 fuel oil	Examples – Very heavy No. 6 fuel oil, residual oils, vacuum bottoms, heavy slurry oils
Specific gravity of < 0.80 Floats on surface	Specific gravity of < 0.85; API gravity of 35-45* Usually floats on surfaces, although can contaminate suspended sediments that are then deposited on the bottom.	Specific gravity of 0.85-0.95; API gravity of 17.5 – 35 * Usually floats on surface, although can mix with sand by stranding on beaches or in the surf zone, and be deposited in the nearshore area.	Specific gravity of 0.95 – 1.00; API gravity of 10-17.5 * Usually floats on surface but can sink in fresh water or in seawater if they emulsify or mix with sand (in the surf zone or after stranding on beaches) and deposit in the nearshore.	Specific gravity greater than 1.00; API gravity < 10 * Will sink in fresh water; may sink in seawater if they emulsify or mix with sand (in the surf zone or after standing on beaches) and deposit in the nearshore.
High evaporation rates; narrow cut fraction with no residues.	Refined products can evaporate to no residue; crude oils do leave residues.	Up to one-third will evaporate in the first 24 hours; will form persistent residues.	Very little product loss by evaporation; will form persistent residues.	Very little evaporation when submerged; also very slow weathering overall when submerged.
Low viscosity; spreads rapidly to a thin sheen; readi8ly dispersed; will not emulsify.	Low to moderate viscosity; spread rapidly into thin slicks; readily dispersed by natural processes; may form unstable emulsions.	Moderate to high viscosity; dispersed by natural processes only very early in the spill; readily emulsifies.	Very viscous to semisolid; will not readily disperse or mix into the water column; can form stable emulsions.	Very viscous to semi-solid; will not readily disperse or mix into the water column; can form stable emulsions.
Low risk of seafood contamination because of rapid and complete loss via evaporation; potential contamination for spills in confined areas with high mixing, such as small rivers; no reported cases of tainting for marine spills.	Moderate to high risk of seafood contamination because relatively high content of low molecular weight, water-soluble aromatic hydrocarbons, which are semi-volatile and so evaporate slowly; dispersed droplets are also bio-available.	Moderate to high risk of seafood contamination because of high percentage of low-molecular weight aromatic hydrocarbons; coating of gear and intertidal species can be significant.	Low risk of finfish contamination because of low water-soluble fraction and little natural mixing in the water; moderate to high risk of shellfish contamination where shoreline oiling is heavy; can coat gear and intertidal species.	Low risk of finfish contamination because of high viscosity; where thick oil accumulates on the bottom, could become a chronic source; moderate to high risk of contamination of benthic species because of coating and persistence of submerged oil.

* API gravity is used by the petroleum industry rather than density. It is determined by the following equation: API at 60º F = 141.5/oil density – 131.5

Of the aromatic hydrocarbons, the mono-aromatic hydrocarbons, such as benzene, toluene, ethyl benzene, xylene (known collectively as BTEX), other substituted benzenes, and the 2- to 3-ringed PAHs (naphthalene, fluorene, dibenzothiophene, anthracene and their substituted homologues, referred to as low-molecular weight

PAHs) comprise over 99 percent of the water-soluble fraction. The distribution of these compounds in the spilled oil is one measure of the potential for contamination of seafood from water exposure.

Compounds in petroleum-derived oils have a general pattern of increasing abundance with higher level of substitution of a benzene ring (*e.g.*, unsubstituted parent naphthalene is less abundant than C1-naphthalene, which is less abundant than C2-naphthalene). This pattern indicates that the PAHs are "petrogenic," that is, they are from petroleum oils. The PAH pattern is very different for hydrocarbons produced from the combustion of fossil fuels ("pyrogenic" hydrocarbons), in that the parent PAHs are by far the dominant compounds in hydrocarbons of pyrogenic origin. Also, it is important to note that crude oils contain very low concentrations of the high-molecular weight PAHs (*e.g.*, 4- and 5-ringed compounds such as pyrene, chrysene, and benzo[a]pyrene) that are associated with combustion by-products. These differences in relative PAH abundance are key components of fingerprinting analysis.

Refined products have characteristic ranges of PAHs representative of the distillation fraction in the product. PAHs in No. 2 fuel oil are dominated by the 2- and 3-ringed compounds. Heavy fuel oils are sometimes cut or blended with lighter fractions to meet customer specifications, as is the case with the intermediate fuel oil (IFO-180), and so can contain some low-molecular weight PAHs.

For exposure via ingestion of whole oil droplets or contaminated sediments, the high-molecular weight PAHs pose greater risk of contamination. These compounds have low water solubility and are more lipophilic. In organisms with relatively limited capability to metabolize PAHs, such as bivalve mollusks, the high-molecular weight compounds are more likely to accumulate in tissues and persist for longer periods, compared to the low-molecular weight PAHs, which are more rapidly eliminated. Finfish and some crustaceans, however, readily metabolize and eliminate all of these compounds rapidly.

Biological and Ecological Factors Affecting PAH Contamination of Seafood

Petroleum contamination of finfish and shellfish depends upon a variety of biological and ecological factors. Understanding how different feeding strategies, habitat utilization, and physiology influence the likelihood of petroleum contamination of particular species is critical when managing seafood after spills. G.2-2 summarizes several of these factors for different types of seafood organisms.

Metabolic Capacity

Both vertebrates and invertebrates have mixed-function oxygenase (MFO) enzyme systems that enable them to metabolize petroleum substances. Enzymatic activity is low in invertebrates compared to vertebrates, and therefore induction of metabolism occurs at a higher contamination level in invertebrates. Finfish are able to rapidly and efficiently biotransform or metabolize PAHs and excrete the resulting metabolites into bile. These metabolites do not pose a health risk to human consumers of the finfish. Marine invertebrates, including most shellfish, metabolize petroleum compounds slowly and inefficiently; consequently, they tend to accumulate high concentrations and wide ranges of PAHs.

Metabolic capacity of organisms is important from a seafood safety standpoint because some PAHs have carcinogenic potential for human consumers, due to the highly chemically reactive oxidation products that form during the first stage of metabolism in vertebrates. Human consumers often eat invertebrates in their entirety, and, therefore, may ingest all of the hydrocarbons that have accumulated in the organism and may be present in the organism's gut. Because finfish, like other vertebrates, rapidly and efficiently metabolize petroleum hydrocarbons, they generally pose little or no health risk to human consumers. Exceptions to this may occur for consumers for whom the edible portion of finfish includes tissues such as liver and gall bladder, which tend to accumulate higher levels of PAHs than muscle tissue.

Temperature

It is generally accepted that uptake and elimination rates both tend to increase with increasing temperature, though there is some contradiction among reported study results for PAHs.

The rate of reaction in chemical and biological processes generally increases 2- to 4-fold for a 10°C increase in temperature. Uptake, metabolic, and elimination rates typically increase with temperature, but at different rates, making it difficult to predict body burdens under the constantly changing oil concentrations that occur at spills. However, at high temperatures and increased respiration and filtration rates, it is expected that uptake will occur quickly, to relatively high concentration, followed by rapid declines. At low temperatures, body burdens are likely to be lower, but elimination rates will also be slower. At very low temperatures, some species stop feeding and thus are at lower risk of exposure.

Table G.2-2 Habitat utilization, feeding strategies, and risk of exposure to oil of different seafood groups.

Seafood groups	Examples	Metabolic capacity	Habitat utilization	Feeding strategies	Risk of exposure
Finfish					
Anadromous fish	Sturgeon, herring, salmon	High capacity	Nearshore and shallow water during spawning	Predatory	Moderate to high in nearshore and shallow water during spawning
Marine pelagic and bottom fish	Mackerel, jacks, cod, flounder	High capacity	Highly mobile, most species prefer depths of > 10m	Predatory	Low
Reef fish	Sea basses, snappers, porgies	High capacity	Relatively deep waters (10 – 200 m)	Predatory	Low to moderate; higher risk in shallow water
Estuarine fish	Bluefish, mullet, anchovies	High capacity	Spawning in intertidal or subtidal habitats; offshore winter migrations	Predatory	Moderate to high in nearshore and shallow water during spawning
Crustaceans					
Lobster, crabs, shrimp	American lobster, pink shrimp, blue crab	Reduced capacity	May migrate seasonally; range of depths between estuarine and deep waters.	Predatory; omnivorous, scavengers	Benthic burrowing, estuarine and shallow water species at higher risk than deep water species
Mollusks					
Oysters, mussels	American oyster, Pacific oyster, blue mussel	Very limited capacity	Shallow subtidal and intertidal regions, estuaries; attached to substrates	Filter-feeders	High
Clams, scallops	Hard clam, soft-shell clam, bay scallop, sea scallop	Very limited capacity	Intertidal and shallow subtidal areas; benthic or buried in the sediment; some mobility	Filter/deposit feeders	High
Gastropods	Abalone, conch, snails, whelk, limpet, top shell	Very limited capacity	Intertidal and shallow to deep subtidal areas; epibenthic; some mobility	Grazers and predatory	Moderate to high

Physiology

Lipid, carbohydrate, and protein levels are known to vary seasonally in certain aquatic invertebrate species, often associated with reproductive changes. Some of these changes in biochemical composition may affect uptake and elimination rates seasonally. Seasonal variation may also result from differences in feeding rates, microbial activity, and various environmental factors.

Organisms with higher overall lipid content generally exhibit higher levels of uptake or retention of petroleum compounds. For example, salmon (muscle lipid content of 4.0% wet weight) accumulated higher hydrocarbon concentrations than cod (muscle lipid content of 0.75% wet weight). Uptake rates of PAHs in clams peaked when gametogenesis was near completion and decreased during spawning, while elimination rates peaked during spawning. Oysters and clams sampled at the high point of lipid and glycogen reserves during their spawning cycles (the fall) had PAH tissue levels that were 2 to 3 times higher than they were when sampled during the spring. High elimination rates during the loss of lipid-rich eggs are consistent with findings that finfish and shellfish tend to accumulate PAHs in tissues with high lipid content because PAHs are strongly hydrophobic.

Potential variations in PAH uptake and elimination rates in seafood species due to seasonal and physiological variation should be taken into account during spill response. These differences should be considered when designing seafood sampling plans and when comparing analytical results from samples from different species, collected at different times of year, or collected during different stages in the life cycle of the organisms.

Chronic Exposure Stress

Bioaccumulation levels and elimination rates of hydrocarbons for finfish and shellfish may depend on the type and duration of exposure to petroleum products, and the extent to which the organisms have been chronically exposed to other contaminants. Chronic exposure appears to reduce elimination capacity. In fact, there may be two phases of elimination: an initial rapid phase followed by a second slower phase for PAHs that are sequestered in stable compartments of the organism, such as storage lipids. Some chronic hydrocarbon pollution studies have indicated no significant reductions in PAH levels in tissues over 2-4 months for clams and mussels, even when the animals were moved to cleaner habitats. The ratio of liver/muscle concentrations in finfish sometimes can be used as an indicator of the level of chronic PAH contamination at a site. Liver levels represent shorter-term exposure to oil, while muscle levels represent longer-term bioaccumulation. Therefore, lower liver/muscle ratios may indicate decreased efficiency in an organism’s ability to biotransform absorbed or ingested oil into compounds that are easily excreted.

Other subsistence and recreational seafood organisms

Some organisms that are collected and consumed for subsistence and recreation were not discussed in this section. Examples are octopus, squid, seals, whales, seaweed, and algae. There isn’t enough information on these organisms to thoroughly discuss the level of risk they may pose to consumers following an oil spill. It should be noted, however, that if these organisms occur in a spill area and are exposed, restrictions on harvest or consumption advisories might be warranted, depending on contamination and consumption levels.

Summary

- Wild finfish are unlikely to become contaminated or tainted because they typically are either not exposed or are exposed only briefly to the spilled oil and because they rapidly eliminate petroleum compounds taken up. Exceptions may occur if a large amount of fresh, light oil is mixed into the water column or if bottom sediments become contaminated. If nearshore sediments are contaminated, species that spawn in nearshore and shallow waters are more likely to be exposed to spilled oil than pelagic and benthic species.
- Penned finfish are more susceptible to tainting and contamination because they are not able to escape exposure.
- Shellfish are more likely than finfish to become contaminated from spilled oil because they are more vulnerable to exposure and less efficient at metabolizing petroleum compounds once exposed.

- Among crustaceans, species that burrow are at the highest risk of exposure at spills where bottom sediments are contaminated, followed by species that utilize nearshore and estuarine benthic habitats.
- Bivalves are at high risk of contamination because they are sessile, filter- and deposit- feed, and occur in substrates in shallow subtidal and intertidal areas that are more likely to become contaminated.
- It is generally accepted that uptake and elimination rates both increase with temperature, though study results are somewhat contradictory.
- PAHs tend to accumulate to higher concentrations in lipid-rich tissues and organisms. Sea-sonal differences in tissue lipid content associated with spawning may influence uptake and elimination rates of PAHs in some marine species.
- Chronic exposure to hydrocarbons in water and sediments may reduce elimination capacity.

MONITORING SEAFOOD FOR CONTAMINATION

The preceding section described information that can help determine the likelihood that spilled oil will expose and contaminate seafood. If it is decided that seafood is at significant risk, the next step is monitoring to determine whether seafood actually is contaminated, and to characterize the extent and degree of contamination. This section provides general guidelines for developing seafood sampling plans and conducting sensory and chemical testing of seafood samples for petroleum contamination.

Developing Seafood Sampling Plans

The first step in developing a sampling plan is defining the questions to be answered. Sampling should not begin before study objectives have been clearly established. Because every oil spill is a unique combination of conditions and the objectives of seafood sampling may vary from spill to spill, there is no standard sampling plan that can be applied to all seafood contamination monitoring studies. Generally, though, any sampling plan to monitor for potential seafood contamination from an oil spill should specify the study area, sampling locations, target species, number of samples to be collected, timing of initial and repeat sampling, sample collection methods and handling procedures, and analyses to be conducted. The statistical design must ensure sufficient statistical power to provide the information needed at the desired level of confidence to support seafood management decisions.

Some general guidelines for designing a seafood-sampling plan are presented below. For more detailed guidelines, see *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories Volume 1: Fish Sampling and Analysis* by the U.S. Environmental Protection Agency (2000). For more detailed sampling guidelines for sensory testing, see *Guidance on Sensory Testing and Monitoring of Seafood for Presence of Petroleum Taint Following an Oil Spill* (Reilly and York 2001).

Selecting sampling locations

In selecting sampling locations, all likely pathways of oil exposure should be identified (*e.g*., surface slicks, dispersed or dissolved oil in the water column, submerged oil associated with bottom sediments), so that risks to specific fisheries can be evaluated. Inclusion of commercial, recreational, and subsistence harvest areas should be considered.

Collection of pre-exposure samples from the spill area or samples from appropriate unexposed reference areas is extremely important because they can provide information on background levels of contamination in the spill area. Petroleum hydrocarbons are ubiquitous in environmental samples, so we cannot assume that all petroleum hydrocarbons measured in a sample or all increases over time are a result of an oil spill. Furthermore, monitoring often continues until the level of contamination returns to “background.” Reference samples are key to determining the range of background concentrations and the baseline against which changes over time will be evaluated.

The best reference samples are pre-spill samples taken in areas not yet oiled but in the potential path of the oil ("before" can be compared with "after" exposure). If pre-spill sampling is not possible, unexposed reference sites comparable to exposed sites can be selected for sampling. However, site histories and differences in the characteristics of the sites should be carefully evaluated to determine whether there are significant differences between the exposed and reference areas. Often, areas that escape oiling do so because they differ fundamentally from exposed areas (for example, bays that face different directions), and so would not be expected to exhibit the same "background" conditions. Any differences between reference and exposed sites must be considered when analyzing and interpreting results.

National monitoring programs such as NOAA's National Mussel Watch Program can provide valuable pre-spill data for determining historical ranges of background concentrations of PAHs in shellfish at several locations around the country. When available for an area, PAH data from the NOAA Status and Trends Program (including the National Mussel Watch Program) or other monitoring programs may help determine normal background levels and seasonal patterns in contaminant levels.

Selecting target species to be sampled

Evaluating risk to human health from seafood consumption usually is a primary purpose of seafood sampling, so including species harvested commercially, recreationally, and for subsistence use may be important. Species that are present throughout the area of concern may be most appropriate for sampling if results are to be compared spatially or if the results are to be used to make statistical inferences to the entire area.

Hydrocarbon uptake and elimination rates vary widely. Finfish, for example, quickly metabolize and eliminate PAHs. Bivalves generally tend to bioaccumulate most contaminants and often serve as good indicators of the potential extent, degree, and persistence of contamination. On the other hand, some shellfish species stop feeding or passing water over their gills at extreme temperatures and, consequently, may exhibit low uptake rates under certain conditions. Consider such differences when selecting species for monitoring and comparing results among species.

Sampling frequency and duration

Monitoring generally should continue until contaminant levels reach background levels or predetermined acceptable levels. Periodic sampling before those levels are reached can reveal trends in contaminant levels. Appropriate monitoring frequency and duration will depend on spill conditions, such as oil type and volume spilled, flushing rates of affected water bodies, and the degree of exposure to wave action of contaminated shorelines. Appropriate monitoring frequency and duration will also depend on the species exposed and exposure duration. Finfish generally eliminate hydrocarbons within days or weeks, whereas bivalves may require several weeks or months. Elevated levels of petroleum compounds in bivalves have been detected for years at some sites where high levels of oil persist in adjacent sediments. Time of year should also be considered in some climates because elimination rates may be slower in cold temperatures. Other factors to consider with regard to monitoring frequency are the turnaround time for sample analysis and time required for the evaluation team to meet, interpret the results, and decide on the need for further sampling. Sampling plans may need to be adjusted over time as conditions change and as monitoring results provide new information on the fate of the oil and on which pathways of exposure are significant.

Sample collection and handling

The seafood-sampling plan should specify all details about sample collection. This includes the areas to be sampled, number of samples to be collected from an area (to meet statistical objectives), number of organisms or quantity of tissue to be composited (to meet analytical requirements), size of organisms to be collected, tidal elevations for collection (in the case of intertidal invertebrates), method of marking or recording exact sampling locations, and field notes to be recorded.

The sampling plan should also specify how seafood samples should be handled. This includes any field preparation, packaging and temperature requirements (for example, wrapping in foil, keeping in a cooler at 4°C or below, and freezing within a specified period of time), labeling, and any chain-of-custody requirements during transport to the analytical laboratory. The edible portion, which may vary culturally, is usually the portion of interest. Seafood samples collected for sensory testing generally should be handled as they would be during commercial, recreational, or subsistence harvest and transport.

Procedures should be followed to prevent cross-contamination in the field (such as preventing exposure of samples or sampling equipment to exhaust fumes and engine cooling systems on vessels) and to maintain the integrity of the samples. Likewise, good laboratory practices should be employed to prevent contamination of samples during preparation and analysis.

Testing Seafood for Contamination and Tainting

Generally, two different types of evaluations can be conducted after oil spills to determine whether seafood is contaminated. Sensory testing determines whether seafood is tainted, *i.e*., if it has an off-odor or off-flavor. Chemical analysis determines whether tissues are contaminated with targeted compounds. Detailed methods of chemical analysis can indicate the presence as well as the quantity of specific contaminants in tissues. These results can be used to evaluate risk to human health through consumption of contaminated seafood. Summaries of these types of seafood testing are described below.

Sensory evaluation of seafood for presence of petroleum taint

When an oil spill occurs, local seafood resources may be exposed to petroleum compounds that affect their sensory qualities; that is, smell, taste, and appearance. Even when seafood from a spill area is considered acceptable with regard to food safety, flavor and odor may still be affected, negatively impacting the seafood's palatability, marketability, and economic value. Furthermore, tainted seafood is considered by the U.S. Food and Drug Administration to be adulterated and, therefore, is restricted from trade in interstate commerce.

Tainted seafood is defined as containing abnormal odor or flavor not typical of the seafood itself (ISO 1992). Under this definition, the odor or flavor is introduced into the seafood from external sources and excludes any natural by-products from deterioration due to aging during storage, decomposition of fats, proteins, or other components, or due to microbial contamination normally found in seafood. Taint is detected through sensory evaluation, which has been defined as "the scientific discipline used to evoke, measure, analyze and interpret those reactions to characteristics of foods and materials as perceived through the senses of sight, smell, taste, touch and hearing" (Food Technology Sensory Evaluation Division 1981). Humans have relied for centuries on the complex sensations that result from the interaction of our senses to evaluate quality of food, water, and other materials. In more recent times, sensory testing has developed into a formalized, structured, and codified methodology for characterizing and evaluating food, beverages, cosmetics, perfumes, and other commercial products. Sensory evaluation techniques are routinely used commercially in quality control, product development, and research. Sensory testing can be either subjective or objective. Subjective testing measures feelings and biases toward a product rather than the product's attributes. For objective testing, highly trained assessors use the senses to measure product attributes. Testing of seafood for petroleum taint should be completely objective and should be conducted by highly trained analysts.

Objective sensory testing serves as a practical, reliable, and sensitive method for assessing seafood quality. Only human testers can measure most sensory characteristics of food practically, completely, and meaningfully. Though advances continue to be made in developing instrument-based analysis, human senses remain unmatched in their sensitivity for detecting and evaluating organoleptic characteristics of food. The U.S. Food and Drug Administration and NOAA's National Marine Fisheries Service routinely employ sensory evaluation in inspecting seafood quality. Seafood inspectors are essentially sensory analysts, or assessors, who work as expert evaluators in the application of product standards. A major objective of seafood sensory inspection is to evaluate quality with regard to decomposition of fisheries products. Sensory analysis can also provide information on presence of taint from external sources, such as spilled oil and chemicals.

Sensory panels

Objective sensory evaluation of seafood is usually conducted using a panel of trained and experienced analysts. Sensory analysts must be screened for sensitivity and then trained in applying established sensory science methodology. Participation in calibration or "harmonization" workshops ensures uniform application of sensory evaluation criteria for particular types of contaminants, including standard terminology and consensus on levels of intensity of sensory characteristics. Descriptive analyses and references are used to yield results that are consistently accurate and precise.

There are different types of sensory analysts, which function differently and have specific selection, training, and validation requirements. *Trained assessors* are sensory analysts selected and trained to perform a specific task. *Expert assessors* are the most highly trained and experienced category of sensory analyst. Expert assessors generally evaluate product full-time, function independently, and often are used in quality control and product development. Examples of products evaluated by expert sensory assessors include wine, tea, coffee, and seafood. Through extensive standardized training and experience with sensory methodology, these expert assessors have become extremely objective and evaluate quality with a high degree of accuracy and precision. Seafood inspectors fall into the category of expert assessors, and can make consistent and repeatable sensory assessments of quality characteristics of seafood as they relate to grade level or decisions to accept or reject product.

The number of panelists needed depends on the level of expertise and experience of the analysts used. For panels of expert assessors, such as NMFS and FDA seafood inspectors, usually only three to five analysts are needed. If less experienced analysts are used, a larger number of panelists is recommended. Whenever possible, use of expert seafood assessors, such as seafood inspectors, is recommended for evaluation of seafood for presence of petroleum taint. Extensive product knowledge and experience enable seafood inspectors to very accurately distinguish variations related to product processing, storage, deterioration, etc. from taint due to external sources. Some seafood inspectors for NMFS and FDA have had specialized training for detecting petroleum taint in seafood and experience evaluating seafood samples at oil spills. If called upon, these specialized inspectors are available to conduct sensory evaluation of seafood during spill events.

Sensory evaluation procedures

Applied as a science, sensory evaluation should be conducted under specific, highly controlled conditions in order to prevent extraneous influences in the testing environment from affecting panelists' sensory responses. Accordingly, sensory testing is best conducted in facilities specifically designed for sensory testing. The NMFS Seafood Inspection Branch maintains several such laboratories around the country. Seafood samples collected during a spill event can be shipped to these laboratories for sensory evaluation. In most cases, NMFS and FDA recommend that samples be shipped and evaluated in the same manner as they normally are shipped and sold (*i.e.*, fresh, live, frozen). When this is not possible, as may be the case for oil spills in very remote areas, sensory analysts can conduct evaluations at the scene of an incident.

All sensory testing should be conducted under the supervision of a sensory professional, who designs and implements the sensory testing procedure. A trained "facilitator" should coordinate sensory analysis. The facilitator conducts the testing, including receiving, preparing, and presenting samples to the expert sensory panel, and collecting the resulting data in a scientific and unbiased manner. All of these steps should be conducted according to standardized procedures under highly controlled conditions. Suspect samples are presented to assessors in blind tests, along with control or reference samples. Samples are first smelled raw, then smelled cooked, and finally tasted by each panelist independently to determine whether petroleum taint is present. A sensory professional statistically analyzes panelist's responses to determine whether samples pass or fail with regard to presence of petroleum taint. These results, in turn, help seafood managers determine whether restrictions are needed on seafood harvest or marketing from the spill area due to tainting.

We are not certain which compounds in petroleum are responsible for taint perceived by humans, so chemical analysis cannot yet substitute for sensory testing in determining whether a taint is present. It has been suggested that the principal components of crude and refined oils responsible for tainting include the phenols, dibenzothiophenes, naphthenic acids, mercaptans, tetradecanes, and methylated naphthalenes. The human olfactory system generally is very sensitive to phenolic and sulfur compounds, even though they are minor components of oil.

In 2001, NOAA published a technical guidance document on appropriate sensory methodology to objectively assess seafood for the presence of petroleum taint. Written by sensory scientists with NOAA's National Marine Fisheries Service Seafood Inspection Program and Canada's Food Inspection Agency, in cooperation with the U.S. Food and Drug Administration, *Guidance on Testing and Monitoring of Seafood for Presence of Petroleum Taint Following an Oil Spill* comprehensively describes recommended standard procedures, including collection, preservation, and transport of seafood samples, for sensory evaluation. The guidance is intended to assist in conducting scientifically sound and legally defensible sensory tests on seafood during oil spill response, with adequate and appropriate quality control.

Chemical testing techniques for petroleum contaminants in seafood

Chemical testing of seafood often is conducted after an oil spill to determine whether seafood tissues are contaminated with petroleum compounds. Both detailed and screening methods of analysis can be employed. Below, we summarize methods typically used after past oil spills, including some of their advantages and disadvantages.

DETAILED METHODS OF CHEMICAL ANALYSIS: GAS CHROMATOGRAPHY/MASS SPECTROMETRY

Detailed chemical analysis of seafood after oil spills typically is conducted using gas chromatography and mass spectrometry (GC/MS), which measures individual PAHs at very low detection levels and provides a PAH pattern (or fingerprint) to compare to that of the source oil. Prior to analysis, hydrocarbons are extracted from seafood tissue samples and the extract is split into three fractions: 1) the saturated hydrocarbons fraction (containing the n-alkanes, isoprenoids, steranes and triterpanes; 2) the aromatic hydrocarbon fraction (containing the PAHs and sulfur heterocyclics; and 3) the polar hydrocarbon fraction (containing the nitrogen heterocyclic compounds. Recovery standards appropriate to each fraction are added.

The PAHs in the fraction generally are of greatest concern with regard to risk to human health. The gas chromatograph separates targeted PAH compounds yielding a retention time that, in combination with the mass spectra from the mass spectrometer, enable detailed identification of individual compounds by their ion masses. The method often used is usually referred to as "Modified" EPA Method 8270, which is EPA Method 8270 for semi-volatile compounds modified to include quantification of the alkyl-substituted PAH homologues, in addition to the standard PAH "priority pollutants." In oil, alkylated homologues of PAHs are more predominant than parent PAH compounds, often by an order of magnitude. This is in contrast to pyrogenic (combustion) and other potential PAH sources. The detailed chemical fingerprint provided by GC/MS analysis enables differentiation among sources of PAHs found in the sample. Contamination from a specific spill can be distinguished from background sources of contamination, such as PAHs derived from combustion sources. GC/MS can also measure analytes other than PAHs to help with fingerprint analysis of oil or to track oil weathering. The GC/MS can be run in the selected ion monitoring (SIM) mode, rather than the full-scan mode, to increase the minimum detection levels (MDL) of the individual parent and selected homologue PAHs by a factor of 10 to 40. Minimum detection levels for individual PAHs are very low, in the range of parts per billion (ng/g) in tissue. The quantitative results for specific, targeted PAHs can be used to assess whether levels detected pose a risk to human health through seafood consumption.

Normal turnaround time for analysis of tissue samples for PAHs is approximately two weeks. Fast turnaround time is approximately three days for a batch of samples. Costs for GC/MS-SIM analysis of tissues are relatively high, starting from about $750 per sample, plus premiums of 50-100% for fast turnaround. The sample-processing rate depends on the throughput capabilities of the laboratory and the degree of quality control (QC) of the data before the results are released, ranging from approximately 20 to a maximum of 100 samples per week.

Data Reporting and Interpretation

The importance of data reporting and interpretation should not be underestimated in plan-ning seafood safety monitoring programs after oil spills. Some simple steps can be taken to help avoid confusion and prevent incorrect conclusions. For example, the analytical laboratory should include at least the following information for all analytical data reported:

Header Information

- *Sample Name or Field ID: the sample name or number assigned by the sampler*
- *Sample Type: e.g., sample, field blank, trip blank, procedural blank, QC*
- *Batch No.: analytical batch number (so samples run as a batch can be identified, particularly if problems are found with a batch run)*
- *Matrix: e.g., water, sediment, tissue, oil*
- *Percent Moisture: for tissue and sediment samples*
- *Sample Size: weight or volume of sample used for analysis*
- *Collection Date: date the sample was collected*
- *Extraction Date: date the sample was extracted*
- *Analysis Date: date the sample was analyzed*
- *Analysis Method: EPA Method or other description*
- *Surrogate Corrected?: Are the reported concentrations corrected for surrogate recovery?*
- *Method Detection Limit: the minimum detection level*
- *Units: units in which the concentration is reported, including whether concentrations are wet weight or dry weight (for tissue)*

Analyte Data

- *Individual and Total PAH concentrations*
- *Surrogate Recovery (%): for every sample*
- *Key to Data Qualifiers: The lab should include a key to any qualifiers used to flag reported values that have some kind of data accuracy issue. For example, two standard qualifiers used under the USEPA Contract Laboratory Program guidelines (USEPA 1994) are:*
- *U = the analyte was analyzed for, but was not detected above the reported sample quantification limit*
- *J = the analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample*

Analysis of the source oil, if available, is needed to enable fingerprint comparisons. Only expert petroleum hydrocarbon chemists should interpret fingerprints because the complex processes of oil weathering and uptake result in variable PAH patterns in organisms. Also, patterns can be difficult to interpret in samples collected from areas with high background levels of contamination.

Caution is advised when comparing analytical results for samples of different types, or samples collected from different areas or at different times. Before drawing conclusions, consider any differences in the analyses conducted or the way the data are reported. Examples of differences to watch for include:

- The units in which results are reported, and whether reported concentrations are dry or wet weight;
- Whether the lists of analytes and minimum detection limits for individual PAHs are the same;
- Whether reported concentrations have been corrected for surrogate recovery; and

- Whether reported concentrations have been lipid-normalized. PAH uptake and retention tend to increase with the increasing lipid content of tissues. Consequently, differences in lipid content may need to be considered when comparing and interpreting analytical results over time or among different organisms.

Rapid screening methods of analysis

Rapid, low-cost analytical methods, generally known as screening methods, can be employed to identify contaminated samples and prioritize them for detailed analysis. Detailed methods of analysis for PAHs in tissue are time-consuming and expensive. The large number of samples often collected after an oil spill can quickly overwhelm laboratory capacity and strain resources. Screening methods of analysis can rapidly process large numbers of samples to yield semi-quantitative estimates of contaminant concentrations and allow ranking of samples by degree of contamination. Used in a tiered approach, screening methods can identify the most contaminated samples, prioritizing or reducing the number of samples that need to be processed by detailed analytical techniques, such as GC/MS.

For example, in response to the need to analyze large numbers of subsistence seafood samples collected after the *Exxon Valdez* oil spill in Prince William Sound, Alaska, NOAA's Northwest Fisheries Science Center used reverse-phase, high performance liquid chromatography (HPLC) with fluorescence detection to screen for metabolites of aromatic compounds in finfish bile. Finfish rapidly metabolize aromatic compounds and concentrate the resulting metabolites in bile for excretion, often at concentrations that are orders of magnitude greater than those in edible tissue. Using this rapid, low-cost method, hundreds of finfish tissue samples were screened for indication of exposure to petroleum contaminants, enabling GC/MS analyses to be focused on selected samples to confirm presence and quantities of individual contaminants. HPLC/UV fluorescence screening methods have also been used for rapidly measuring aromatic compounds in invertebrate tissues. This screening method was used successfully on lobster samples collected after the *North Cape* oil spill off the coast of Rhode Island in 1996.

Screening analyses, such as the HPLC/fluorescence method described above, generally can be completed in rapid turnaround time (within 24 hours) and can be conducted on a research vessel or onshore lab. Rapid availability of results enables sampling modifications based on indications of exposure. This can be very helpful during the critical early phases of an oil spill response, when decisions regarding closing or otherwise restricting seafood harvest may be made.

The utility of HPLC/fluorescence and other screening methods, however, is more limited than detailed methods of analysis. For example, though it may be possible to recognize chromatographic patterns associated with characteristic classes of petroleum products, HPLC/fluorescence screening does not produce a detailed "fingerprint" similar to the results acquired from GC/MS. Consequently, HPLC/fluorescence usually will not enable differentiation between background contamination sources and the spilled oil, especially in very polluted areas. Since HPLC/fluorescence screening does not quantify individual aromatic compounds, the results cannot be used to assess risk to human health from consumption of contaminated seafood. Furthermore, measurement of fluorescent aromatic compounds in bile is not a standard analysis, limiting temporal and spatial comparisons using historical data sets. Lastly, HPLC/fluorescence screening for fluorescent aromatic compounds in bile is a specialized technique, and laboratory availability and expertise needed to conduct the analyses reliably may be limited.

Water Monitoring

Water samples often are collected and analyzed as part of the initial spill response and assessment. Seafood safety managers can use these results to help estimate the extent and duration of seafood exposure to oil in the water column. Monitoring water concentrations may also be important if water-quality criteria are applied as a condition for reopening a closed fishery or removing other harvest restrictions.

Oil concentrations in the water column generally peak early after an oil spill and, in most cases, rapidly decline to background levels within days to a week, as was the case for example at the *New Carissa* oil spill. Accordingly, if water sampling is to be conducted, initial sampling should commence very soon after a spill occurs. Oil may persist longer than usual in the water column if there are multiple or ongoing oil releases, if the released volume is extraordinarily large, or if large volumes of oil are physically dispersed. After the *Braer* oil spill, for example, elevated oil concentrations were detected in the water column as long as 50 days after release. Dissolved and dispersed oil plumes in the water column are driven by currents and so may have a very different spatial distribution than surface slicks, which are driven primarily by wind.

Under the authority of the Clean Water Act (63 FR 68354-68364), EPA has issued national recommended water-quality criteria for priority toxic pollutants to be used by states and tribes in adopting water quality standards. EPA has issued water-quality criteria for protection against human health effects for three mono-aromatic hydrocarbons and eight PAHs (listed in Table G.2-3). These particular compounds, however, are present in crude oils and refined products at very low levels and constitute a tiny percentage of the PAHs normally detected in water samples after an oil spill. None of the water quality criteria to protect aquatic communities (both freshwater and saltwater) issued by EPA are for PAHs. EPA has issued recommended water quality criteria for organoleptic effects for 23 chemicals, though not for any of the compounds present in petroleum products. Some states have established state water quality standards for PAHs in their coastal waters.

Sediment Monitoring

Sediment monitoring can be included as part of a post-spill monitoring program to determine whether sediments may be a potential chronic source of oil exposure to adjacent seafood collection sites, particularly at intertidal sites where bivalves are harvested. Sediment sampling also may facilitate fingerprint analysis of PAHs in tissues by providing the PAH pattern in contaminated sediments, which may be different than the PAH pattern in the fresh source oil. It is important to recognize, however, that sediments often contain high levels of background PAH contamination, particularly in urban areas and harbors. PAHs and other contaminants detected may not be

related to a particular oil spill. Also, characterization of sediment contamination can be difficult because of the inherent heterogeneity of intertidal sediments over space, depth, and time.

There are no national sediment quality criteria for PAHs in marine or freshwater sediments. Some states have established sediment quality standards and cleanup screening levels to prevent adverse biological effects. How these standards would relate to seafood adulteration or safety issues is unclear.

Table G.2-3 National recommended water quality criteria for priority toxic pollutants for protection agains human health effects.

PAH priority pollutant	Human health criteria for consumption of water + organism (µg/L)	Human health criteria for consumption of organism only (µg/L)
Benzo[a]anthracene	0.0044	0.049
Benzo[a]pyrene	0.0044	0.049
Benzo[a]fluoranthene	0.0044	0.049
Benzo[k]fluoranthene	0.0044	0.049
Dibenzo[a]anthracene	0.0044	0.049
Fluoranthene	300	370
Fluorene	1300	14000

SEAFOOD RISK ASSESSMENT

(Risk assessment and determination of caner risk should be conducted by the California Department of Health Services).

Several different endpoints can be considered when assessing risks posed to human health from consuming contaminated seafood. These include both carcinogenic and non-carcinogenic effects to the general population, as well as to particularly susceptible segments of the population such as children, pregnant women, and subsistence seafood consumers. Human epidemiological studies, when available, and laboratory studies involving animals are used to assess the likely effects of contaminants at various exposure levels.

Evidence from occupational studies of workers exposed to mixtures of PAHs indicates that many of these compounds may be carcinogenic to humans. Individual PAHs that are considered to be probable human carcinogens include benz[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, dibenz[a,h]anthracene, and indeno[1,2,3-cd]pyrene (IRIS 1994). Most of the data gathered from laboratory studies provides information on carcinogenic effects of lifetime exposure to PAHs. Information on non-carcinogenic effects is limited. Consequently, cancer generally is the primary endpoint considered when assessing potential risks to human health from consumption of seafood from an oil spill area.

Seafood Advisory and Action Levels from Previous U.S. Oil Spills

The action or advisory levels resulting from cancer risk calculations differ among spills, depending on the assumptions made and input values selected. At the *New Carissa* oil spill, the Oregon Health Division calculated action levels for average and upper end shellfish consumers of 45 ppb BaP equivalents (BaPE) and 10 ppb BaPE, respectively. Action levels derived by the California Department of Health Services for average and upper-end shellfish consumers following the *Kure* spill were 34 ppb BaPE and 5 ppb BaPE, respectively. At the *North Cape* oil spill, the Rhode Island Department of Health essentially applied a BaPE criterion of 20 ppb for the maximally exposed lobster consumer over the five-year exposure duration. Action levels calculated by the Maine Bureau of Health for lobster consumption after the *Julie N* oil spill for ten and 30- year exposure durations were 50 ppb and 16 ppb BaPE, respectively. Advisory levels for subsistence consumers after the *Exxon Valdez* oil spill, assuming a ten-year exposure period, were three ppb BaPE for salmon, five ppb BaPE for finfish, 11 ppb BaPE for crustaceans, and 120 ppb BaPE for bivalve mollusks. Advisory levels based on a lifetime exposure assumption were approximately an order of magnitude lower. None of the finfish or shellfish samples collected from harvesting areas near Prince William Sound exceeded these advisory levels. Interestingly, the upper-bound lifetime cancer risk for Alaskan subsistence seafood consumers eating the most contaminated bivalve mollusks from the spill area was calculated to be two orders of magnitude lower than the lifetime risk calculated for consumers of locally smoked salmon

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At several of these spills, the calculated action levels were used as recommended levels for reopening harvest of closed seafood fisheries. For example, at the *New Carissa* oil spill, shellfish were considered safe if all samples contained less than 10 ppb BaP equivalents. If any shellfish tissue levels were above 45 ppb BaP equivalents, shellfish in those areas would be considered unsafe, and further monitoring considered necessary. If samples contained more than 10 ppb but less than 45 ppb BaP equivalents, the need for further monitoring would be assessed on a case-by-case basis. A similar tiered approach was used at the *Kure* oil spill. If all samples contained less than 5 ppb BaP equivalents, shellfish beds could be reopened. If any samples contained between 5 and 34 ppb BaP equivalents, the need for further action before reopening would be assessed. If any samples contained more than 34 ppb BaP equivalents, additional sampling and environmental monitoring prior to reopening would be considered.

The Equivalency Approach for Risk Assessment

The equivalency approach used in relative cancer risk assessment is a method used for assessing the risk of exposure to a mixture of several different compounds that are related in terms of chemical and biological activity. Rather than calculating individual risks for each compound, one component of known potency is used as a standard. Concentrations of each of the other compounds are adjusted based on their estimated potency relative to the standard, to calculate an equivalent concentration for the standard. Summing the equivalent concentrations yields a single number from which the cancer risk can be estimated.

This toxicity equivalency approach has been widely used for mixtures of dioxins and furans, for example. The relative potencies of individual dioxin and furan compounds are expressed in terms of 2,3,7,8-tetra-chlorodibenzo-*p*-dioxin (2,3,7,8-TCDD) equivalents. 2,3,7,8-TCDD was chosen as the standard by which the potency of individual dioxin and furan compounds are estimated because most laboratory studies on the effects of dioxins have been conducted using 2,3,7,8-TCDD. Data are more limited on the effects of other congeners. The same approach can be used with petroleum compounds, which also occur in complex mixtures.

SEAFOOD TAINT RISK COMMUNICATION

Both technical and social factors should be considered when communicating information on the health and safety of seafood following an oil spill, particularly when dealing with different groups. The risks and consequences have different meanings for the subsistence user, sport fisher, average consumer, commercial fisher, elected official, regulator, and responsible party representative. Regulators and scientists measure risk quantitatively and accept the uncertainty inherent in the risk-assessment process. The public perceives risk more qualitatively and subjectively, and is influenced by prior experience with similar risks and information made available to them. The public wants to know whether the seafood is safe to eat; yet the answers given are typically posed in terms of “acceptable risk” or “not a significant risk.” Risk communicators should be aware of and try to overcome: 1) gaps in knowledge, 2) obstacles inherent in the uncertainties of scientific risk assessment, and 3) barriers to effective risk communication.

Please see Appendix F for further general information on risk communication approaches and techniques. In addition:

- Meet directly with groups such as commercial fishing associations, recreational users, subsistence users, seafood vendors, etc. Meetings can fail if the risk communicators are not prepared or knowledgeable, or appear to be withholding information. Specialized bulletins or communication methods may be necessary for special groups, such as Native American subsistence users and non-English-speaking users.
- Use unambiguous terms whenever possible. Health risks are commonly described in terms of probabilities of cancer based on assumed consumption rates and periods. It is assumed that carcinogens do not have safe thresholds for exposures; that is, any exposure to a carcinogen may pose some cancer risk (USEPA 2000b). However, it is both useful and appropriate to define “safe” and “unsafe” levels of PAHs in seafood based on risk rates that are commonly considered to be acceptable. For example, water-quality criteria for carcinogenic contaminants in water usually use risk rates in the range of 10^{-5} to 10^{-6}. The general public understands the concepts of acceptable risks, although there may be components of society where these risks conflict with local cultures, such as the Alaska Native subsistence users during the *Exxon Valdez* oil spill. As long as the risk communicators clearly define what is meant by “safe” and “unsafe,” these terms are appropriate.

Communicating Relative Risks

Risk communicators commonly compare the relative risk of a specific activity to known risks of other activities. For example, the public is accustomed to hearing the risks of death by automobile accident or airplane crash. These are considered voluntary risks taken by people who decide to drive or fly after considering the risks and benefits associated with these activities, whether or not their perceptions are realistic. The public generally will accept risks from voluntary activities that are roughly 1,000 times greater than involuntary risks that provide the same level of benefits.

Because the potential human-health risks from eating seafood contaminated by an oil spill are associated with PAHs, it is tempting to compare the PAH levels in seafood samples with those found in other food sources. PAHs are ubiquitous contaminants, measurable in many foods. Based on information from previous spills, PAH levels in seafood from oil-spill-contaminated waters generally are considerably lower than PAH levels found in smoked foods. During the *Exxon Valdez* oil spill, however, village community residents became upset when it was pointed out that samples of smoked fish from the villages contained carcinogenic hydrocarbon levels hundreds of times higher than any shellfish samples collected from oiled beaches, and nearly 10,000 times higher than wild salmon. The residents considered eating smoked salmon to be an acceptable, voluntary risk, and eating oil-contaminated seafood to be an involuntary, unacceptable risk. Guidelines for risk communication include being sensitive to the distinction between voluntary and involuntary risk, and avoiding risk comparisons that equate the two. Risk comparisons should be made carefully.